MIDDLE PLEISTOCENE TERRACE EVOLUTION IN THE DRAINAGE OF THE NATORI RIVER NORTHEAST JAPAN

Takayuki KAWAI*

Abstract Reconstruction of evolution of the Middle Pleistocene fluvial terraces in the drainage of the Natori River in Northeast Japan is important to understand how climate, sea-level changes, and crustal movements have controlled geomorphic development, particularly tectonic separation between the Tohoku Backbone Range and the basins located at the foot of the range. The purpose of this study is to clarify the chronological framework of the geomorphic development of these terraces. To reconstruct geomorphic evolution within a chronological framework, marker tephras; Adachi-Medeshima (Ac-Md), Tsubonuma Air-fall Pumice 4-2 (TbP4-2: MIS 7.4–5.2), Tsubonuma Air-fall Lithic Fragment (Tblf: MIS 7.4–5.2), Magarizaka Ash (MgA: MIS 7.4 or MIS 7.2) and the Tsubonuma Air-fall Pumice1 (TbP1: MIS 9), in descending order, were used. This study classified and newly defined the terrace surfaces in the study area into Imo-toge Surface, Moto-isago 1 and 2 surfaces, Aobayama 1 to 4 surfaces, Dainohara Surface and lower surfaces from older to younger. Imo-toge and Moto-isago 1 surfaces would have been formed as fluvial fans before MIS 9 based on stratigraphic relationship with the TbP1. Based on the deformation of the Moto-isago 1 Surface, tectonic separation of the Kawasaki Basin from the Tohoku Backbone Range finished after MIS 10. Aobayama 1 to 4 and Dainohara surfaces would have evolved in the period from MIS 7.5 to MIS 5.2 reflecting climate or eustatic sea-level changes.

Key words: Natori River, fluvial terrace, tephrochronology, Middle Pleistocene

1. Introduction

Middle Pleistocene fluvial terraces are well-developed along the rivers originating from the Tohoku Backbone Range, northeast Japan. It is important to reconstruct evolution of the Middle Pleistocene “higher terraces” for understanding controlling factors on geomorphic development; such as climate change, sea-level change, and/or crustal movements have controlled geomorphic development. Although investigation on higher terraces in the drainage of the Natori River, Miyagi Prefecture is particularly important for reconstructing tectonic separation of the Tohoku Backbone Range and neighboring basins, few previous studies have been attempted (e.g. Nakagawa *et al.* 1960, 1961; Otsuki 1987; Toyoshima *et al.* 2001; Hataya *et al.* 2005). The purpose of this study is to clarify the chronological framework of evolution of the higher terraces in the drainage of the Natori River.

* Kokusai Kogyo, Co. Ltd.

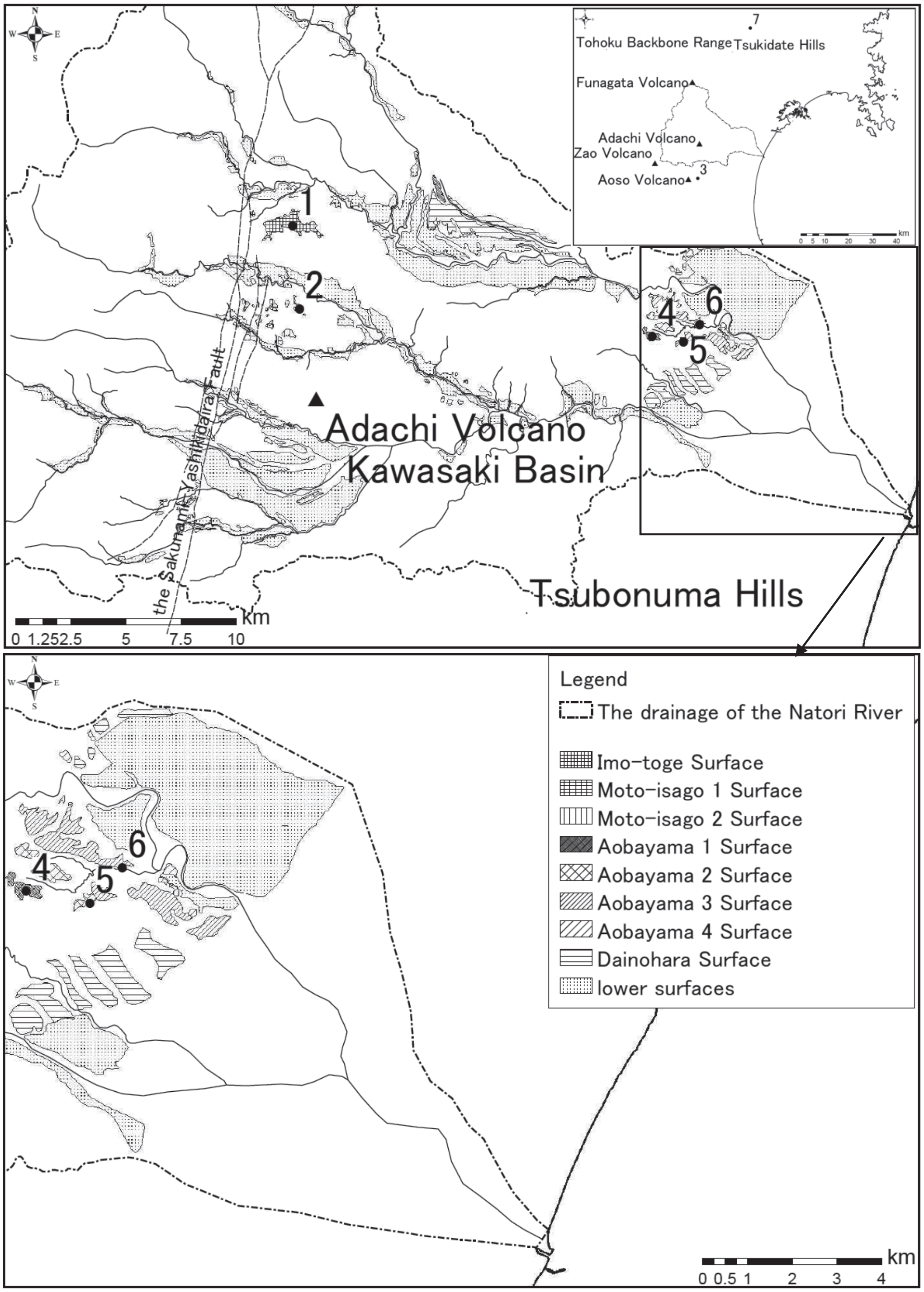

Fig. 1 Classification of the terrace surfaces in the drainage of the Natori River.

2. Maker Tephras

To reconstruct evolution of the terraces within a chronological framework, the following marker tephras, Adachi-Medeshima (Ac-Md; Nakagawa *et al.* 1960), Tsubonuma Air-fall Pumice 4-2 (TbP4-2; Otsuki 1987), Tsubonuma Air-fall Lithic Fragment (Tblf; Otsuki 1987), Magarizaka Ash (MgA; Soda 1989) and Tsubonuma Air-fall Pumice1 (Tblf; Otsuki 1987), in descending order, were used. To correlate between the tephras yielded at the outcrops in and around the study area, stratigraphy and the refractive indices of hornblende, cummingtnite, orthopyroxene, and volcanic glass shards were used.

Ac-Md

Ac-Md originated from the Adachi Volcano near the Kawasaki Basin (Kanisawa 1985) is distributed in the drainage of the Natori River and the Tsubonuma Hills (Nakagawa *et al.* 1960; Otsuki 1987) and is observed at Locs. 4 and 5 (Figs. 1 and 2). This tephra contains cummingtnite (n_2: 1.660–1.665), magnetite, quartz, plagioclase and pumice-type volcanic glass shards (n: 1.500–1.504). Soda (1989) reported Ac-Md was located below Aso-4 (marine isotope stage (MIS) 5.2; Aoki 2008). Hence, stratigraphic position of the Ac-Md was estimated as MIS 5.3 to MIS 7 (Toyoshima *et al.* 2001; Hataya *et al.* 2005).

TbP4-1 and Tblf

TbP4-1 and Tblf are located below Ac-Md and distributed in the Tsubonuma Hills and drainage of the Natori River (Fig. 1). Tblf is intercalated between TbP2 and TbP1. The sources of all of these tephras are unknown (Otsuki 1987). At Loc. 1 (Figs. 1 and 2), Otsuki (1987) described TbP1, 2, 4 and Tblf occur in the eolian loam. The observations in this study revealed that the loam intercalates several paleo red-soil zones, which suggest repetition of warmer climate (e.g. Matsui and Kato 1962) between TbP1, 2, 4 and Tblf depositions.

At Loc. 3 (Figs. 1 and 2), TbP1 occurs 3 m above a pumice flow deposit derived from the Aoso Volcano (Otsuki 1987) and characterized by banded-pumice. Magatake Pumice Flow Deposit (Mg-pfl) contains banded-pumice among the pumice flow deposits derived from the Aoso Volcano (Toya and Ban 2001), therefore, the pumice flow deposit below TbP1 at Loc. 3 is correlated to Mg-pfl.

MgA

At the base of the eolian loam (50 cm below the Tblf) on Loc. 5 (Figs. 1 and 2), a 25 cm thick weathered ash overlies a peat layer comprising terrace deposit of the Aobayama 2 Surface. As described later, Aobayama 2 Surface was formed during the later half of the Middle Pleistocene; therefore the stratigraphic position of the ash is estimated to be in the later half of the Middle Pleistocene. Whereas at Loc. 1, a 50 cm thick weathered ash is intercalated in paleo red-soil between TbP1 and Tblf; the weathered ash recognized at Locs. 1 and 5 contain hornblende (n_2: 1.672–1.680), orthopyroxcene (γ: 1.713–1.721), magnetite, quartz, plagioclase and weathered volcanic glass shards. These properties correspond to those of MgA in the Tsukidate Hills (Soda 1989) with an estimated age of 200–260 ka, which contains hornblende (n_2: 1.671–1.685), orthopyroxene (γ: 1.712–1.724), magnetite, quartz, plagioclase and pumice-type volcanic glass shards (Matsu'ura 2003). Based on the composition changes of plant opal in the Tsukidate Hills,

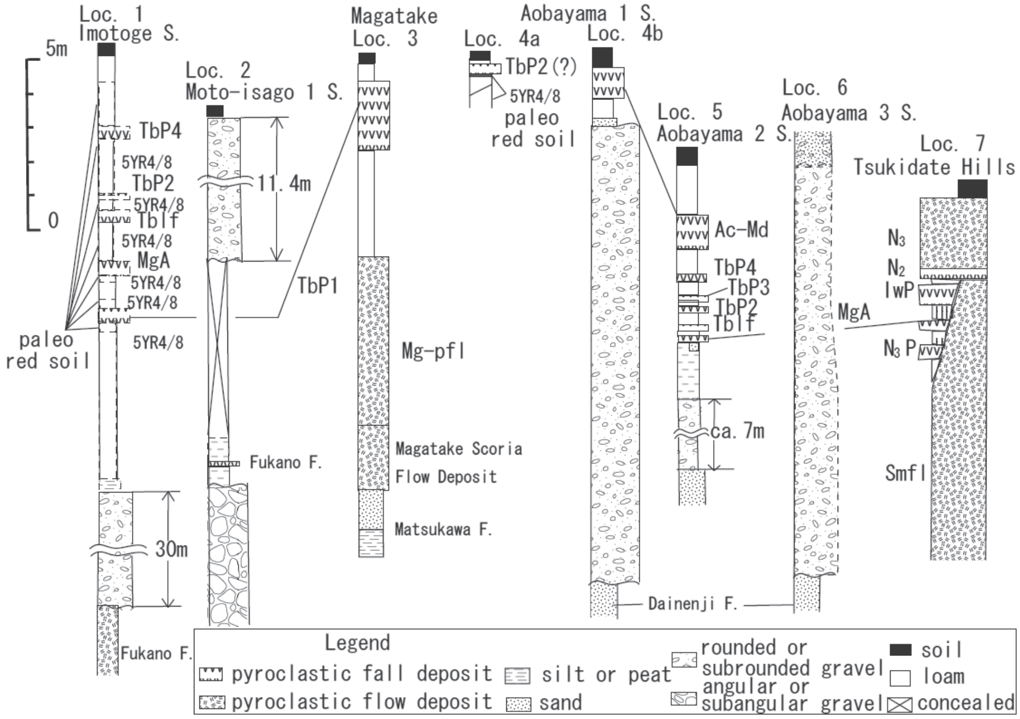

Fig. 2 Columnar sections around the drainage of the Natori River.

MgA was estimated as being deposited in a cooler climate period (Sugiyama and Soda 1996).

3. Classification of terrace surfaces

In this study, terrace surfaces are classified from older to younger as Imo-toge Surface, Moto-isago 1 and 2 surfaces, Aobayama 1 to 4 surfaces, Dainohara Surface and lower surfaces.

Imo-toge and Moto-isago 1 and 2 surfaces

Otsuki (1987) first recognized fluvial terrace surfaces around Locs. 1 and 2 (Fig. 1). These terraces are newly classified into Imo-toge and Moto-isago 1 and 2 surfaces from higher to lower, based on their dissection and vertical distance from the present riverbed to terrace surfaces. The Imo-toge Surface with 30 m thick of terrace deposit (Loc. 1; Fig. 2) is 250–260 m above from the present riverbed and is broadly distributed around Locs. 1 and 2 (Fig. 1). Therefore, Imo-toge Terrace would have been formed as fluvial fan under favorable condition for deposition.

Moto-isago 1 and 2 surfaces are 140–240 m above from the present riverbed. The Moto-isago 1 Surface has 15 m thick terrace deposit (Loc. 2; Fig. 2). Moto-isago 2 Surface, which is the youngest and narrowest surface around Locs. 1 and 2 (Fig. 1), is distributed as a strath terrace on Moto-isago 1 Surface. Therefore, Moto-isago 1 Terrace deposit would have been formed under favorable condition for deposition rather than that of Moto-isago 2 Terrace deposit.

Aobayama 1 to 4 and Dainohara surfaces

Around Locs. 4, 5 and 6, fluvial terrace surfaces are distributed 20–160 m above the present riverbed. All of them are covered by Ac-Md (Nakagawa *et al.* 1961), whereas only the Aobayama 1 and 2 surfaces are covered by TbP4-2 and Tblf (Otsuki 1987).

Aobayama 1 Surface is comprised by 14 m thick weathered terrace deposit and covered by paleo red-soil at Loc. 4 (Figs. 1 and 2). The level of the paleo red-soil is close to the top of the terrace deposit, so Aobayama 1 Surface would have been formed under high sea-level and warmer climate.

The Aobayama 2 to 4 surfaces are distributed around Locs. 5 and 6 (Fig. 1). Vertical distance from the present riverbed to these surfaces are no more than 15 m, therefore, Aobayama 1 to 4 surfaces were possibly formed reflecting sub-stage scale climate or sea-level changes. According to Takeuchi and Yoshida (2010), terrace deposits both of the Aobayama 2 and 3 surfaces are estimated to have been deposited under cooler climate conditions based on pollen fossil assemblages. Whereas, thicknesses of the terrace deposits of Aobayama 2 and 3 surfaces are 7 m and over 10 m (Locs. 5 and 6; Fig. 2), respectively. Furthermore terrace deposit of the Aobayama 2 Surface erodes the Pliocene sedimentary rock horizontally and the Aobayama 4 Surface distributes eroding the edge of the Aobayama 3 Surface; thus, the Aobayama 2 and 4 Surfaces are thought to be strath terraces formed under low sea-level conditions.

Dainohara Surface is broadly distributed south of the Aobayama 1 to 4 surfaces (Fig. 1); therefore, the surface is estimated to have been formed as fluvial fan. However, the precise mechanism of Dainohara Surface formation could not be determined because the details of the terrace deposit could not be observed.

Lower surfaces

Lower terraces have been divided into the Kawauchi Terrace, Uwamachi Terrace, Nakamachi Terrace Group and Shimomachi Terrace Group from older to younger (Nakagawa *et al.* 1960, 1961). None of these terraces are covered by Ac-Md. Only the oldest Kawauchi Surface in the Kawasaki Basin is covered by Aso-4 (Hataya *et al.* 2005). Therefore, the lower terraces are estimated to have been formed during the Late Pleistocene.

4. Discussion and Conclusions

Tephrochronology

In this study, stratigraphic context of MgA and TbP1 in the drainage of the Natori River newly recognized. MgA was deposited in cooler climate (Sugiyama and Soda 1996) during 200 to 260 ka (Matsu'ura 2003). Taking account of a possibility that Aobayama 1 to 4 terraces were formed reflecting sub-stage scale climate or sea-level changes, stratigraphic position of Aobayama 2 Terrace and directly overlying MgA are estimated as being correlated with MIS 7.4 or 7.2. Whereas, tephras from Tblf to TbP4 were deposits before the Aobayama 3 Terrace formation because of deficiency above the Aobayama 3 Terrace (Fig. 3). Moreover, Tblf to TbP4 are located below Ac-Md, which is below Aso-4 (MIS 5.2) according to Soda (1989). Hence, stratigraphic positions of Tblf to TbP4 are correlated to MIS 7.4 to 5.2.

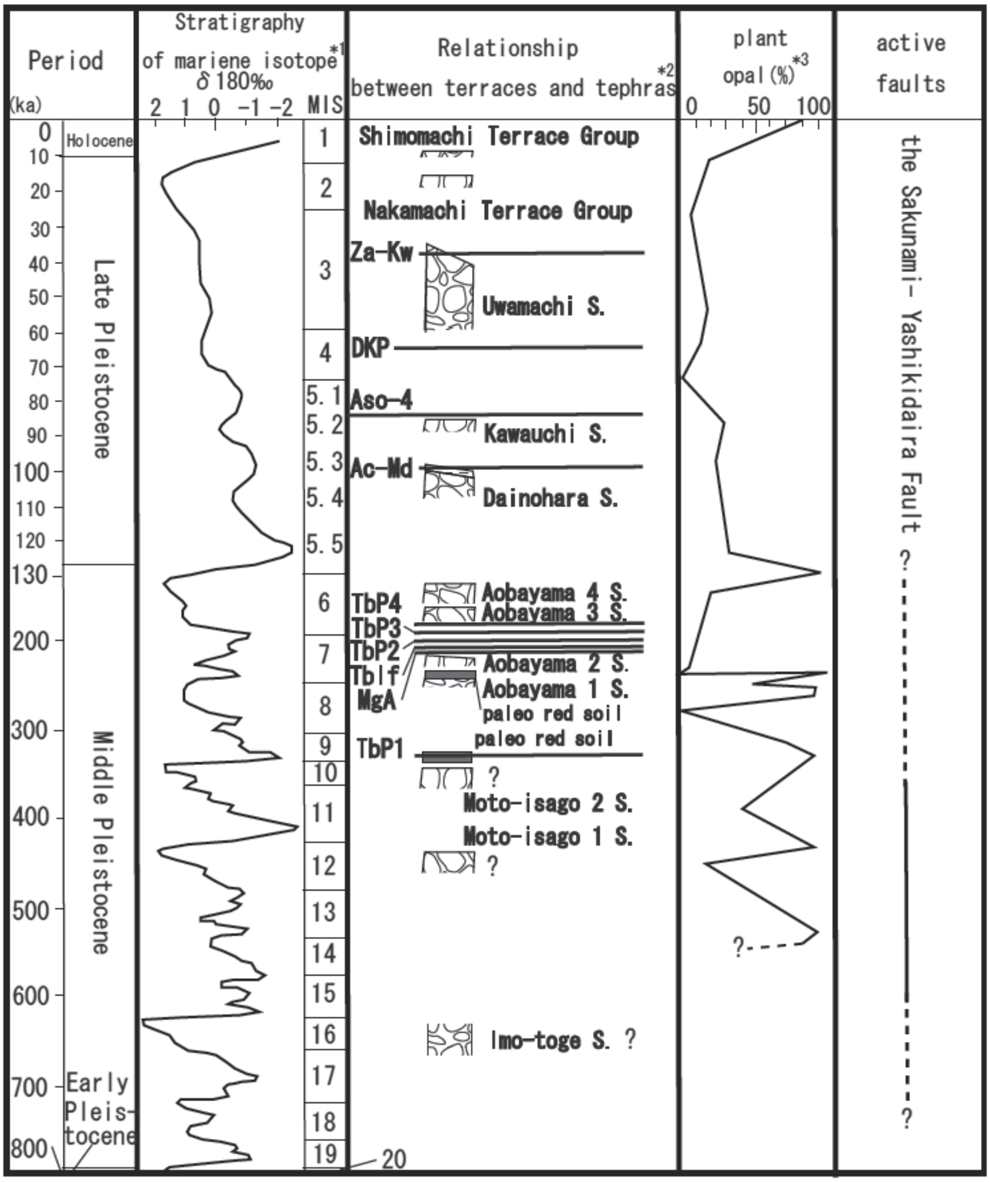

Fig. 3 Chronology of the geomorphic surfaces in the drainage of the Natori River.
*1 Lisiecki and Raymo (2005) *2 Hataya *et al.* (2005) *3 Sugiyama and Soda (1996)

On the other hand, depositional ages of TbP1 and Mg-pfl are younger than 0.38–0.40 Ma based on K-Ar ages of the pyroclastic flow deposit underlying Mg-pfl (Ban *et al.* 1992; Toya and Ban 2001). In addition, intercalation of TbP1 into a red-soil at Loc. 1 (Fig. 2) suggests that TbP1 would have deposited during a warmer climate period. Because of deficiency above the Aobayama 1 to 4 surfaces, TbP1 may be correlated to MIS 9 (Fig. 3).

Geomorphic evolution

Based on the relationship between tephrochronology and terrace surfaces distributed in the study area, the evolution of the higher terraces in the drainage of the Natori River is estimated as follows:

1) Imo-toge and Moto-isago 1 and 2 surfaces were formed before MIS 9 based on the stratigraphic position of TbP1. Imo-toge and Moto-isago 1 surfaces are broadly distributed rather than Moto-isago 2 Surface despite developed dissection of these surfaces. Hence, Imo-toge and Moto-isago 1 surfaces would have been formed reflecting detritus production and supply from the Tohoku Backbone Range under conspicuous cooler climate condition. Therefore, Imo-toge and Moto-isago 1 surfaces would have been formed around MIS 16 and MIS 10, respectively.

2) Sakunami-Yashikidaira Fault separating the Tohoku Backbone Range and the Kawasaki Basin would have deformed the terrace surfaces (Amano 1980), which are classified as the Moto-isago 1 Surface in this study (Fig. 1). Therefore, tectonic separation of the Kawasaki Basin from the Tohoku Backbone Range would have finished after MIS 10 based on the stratigraphic position of Moto-isago 1 Terrace deposit.

3) The Aobayama 1 to 4 and Dainohara surfaces would have evolved in the period from MIS 7.5 to 5.2 (Fig. 3) reflecting climate or sea-level changes. The Aobayama 1 Surface formed during warmer climate condition was correlated to MIS 7.5 or 7.3, whereas, Aobayama 2 Terrace formed as strath terrace during cooler climate condition was correlated to MIS 7.4 or 7.2. After depositions of MgA, Tblf and TbP2-4, Aobayama 3 and 4 and Dainohara surfaces was formed. Although Aobayama 3 Surface is characterized by thick (> 10 m) terrace deposit, the previous pollen fossil study (Takeuchi and Yoshida 2010) suggested the deposit was formed during cooler climate. These facts suggest that besides climate and/or sea-level changes, additional factor might have affected formation of the terrace.

Acknowledgements

I wish to thank Prof. Haruo Yamazaki, Prof. Takehiko Suzuki and the other member in the Laboratory of Geomorphology and Quaternary Geology at TMU for their encouragement and constructive criticism during this study. I am also grateful to Prof. Naoto Koiwa at Hirosaki University and Dr. Toshikazu Tamura for valuable discussions.

References

Amano, K. 1980. Geology of the Ou Backbone Ranges in Miyagi and Yamagata Prefectures, Northeast Honshu, Japan. *Contribute of Institute of Geology and Paleontology Tohoku University* **81**: 1–56.**

Aoki, K. 2008. Revised age and distribution of ca. 87ka Aso-4 tephra based on new evidence from the northwest Pacific Ocean. *Quaternary International* **178**: 100–118.

Ban, M., Oba, Y. Ishikawa, K. and Takaoka, N. 1992. K-Ar dating of Mutsu-Hiuchidake, Osoreyama, Nanashigure and Aoso volcanoes of the Aoso-Osore volcanic zone –The formation of the present volcanic zonation of the Northeast Japan arc–. *Journal of Mineralogy,*

Petrology and Economic Geology **87**: 37–49.**
Hataya, R., Yanagida, M., Sato, M. and Sasaki, T. 2005. Recognition of the Marine Oxygen Isotope Stage 6 fluvial terrace in Kawasaki Basin, Miyagi Prefecture, and its significance. *The Quaternary Research (Daiyonki Kenkyu)* **44**: 155–167.**
Kanisawa, S., The Medeshima Pumice and lithic fragments around Sendai Area –Estimation of source vent existence of extremely low K tonalities–. *Journal of Mineralogy, Petrology and Economic Geology* **80**: 352–362.**
Lisiecki, L., E. and Raymo, M., E. 2005. A Plio-Pleistocene stack of 57 globaly distributed benthic $\delta^{18}O$ records. *Paleoceanography* **20**: PA1003. doi:10.1029/2004PA001071.
Matsui, T. and Kato, Y. 1962. Notes on paleopedology of red soils in Japan. *The Quaternary Research (Daiyonki Kenkyu)* **2**: 161–179.**
Matsu'ura, T. 2003. Tephrostratigraphy of the Shinjo Basin, Yamagata Prefecture, Northeast Japan, in the later half of the Middle Pleistocene. *Geographical Review of Japan* **76**: 142–160.**
Nakagawa, H., Ogawa, S. and Suzuki, Y. 1960. Quaternary geology and Geomorphology of Sendai and its environs (1). *The Quaternary Research (Daiyonki Kenkyu)* **1**: 219–227.**
Nakagawa, H., Sohma, K., Ishida, T. and Takeuchi (Ogawa) S. 1961. Quaternary geology and geomorphology of Sendai and its environs (2). *The Quaternary Research (Daiyonki Kenkyu)* **2**: 30–39.**
Otsuki, Y. 1987. The Mid-Pleistocene marker-tephras in the southern central parts of Miyagi Prefecture, northeastern Japan. *Annual Reports of Tohoku Geography Association* **39**: 268–282.**
Soda, T. 1989. Tephrochronological study of the layers including the early paleolithic artifacts in the northern part of Sendai Plain, Japan. *The Quaternary Research (Daiyonki Kenkyu)* **28**: 269–282.**
Sugiyama, S. and Soda, T. 1996. Phytological study on Takamori Site and its surroundings. *Programme and abstracts of Japan Quaternary Association* **26**: 126–127.*
Takeuchi, S. and Yoshida, A. 2010. Pollen fossil assemblage of Aobayama Formation in the Sendai area, northern Japan. *The Quaternary Research (Daiyonki Kenkyu)* **49**: 233–236.**
Toya, N. and Ban, M. 2001. Volcanic history and major element bulk chemistry of the Aoso volcano, Northeast Japan arc. *Journal of Mineralogy, Petrology and Economic Geology* **30**: 105–116.**
Toyoshima, M., Soda, T. Kitamura, S. and Arai, F. 2001. Chronological review of the Dainohara Terrace in the Sendai Area, northeastern Japan. *The Quaternary Research (Daiyonki Kenkyu)* **40**: 53–59.**

(*: in Japanese, **: in Japanese with English abstract)